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A methodology for creating a virtual model for a flexible manufacturing system

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Abstract

Proposed in the paper is an object-oriented methodology to create a virtual flexible manufacturing system (FMS) model. The proposed virtual FMS model consists of four types of objects: *the virtual device model* (*object model*), *the transfer handler model* (*functional model*), *the state manager model*, *and the flow controller model* (*dynamic model*). A virtual device model consists of two parts: *shell* and *core*. To improve the reusability of a *virtual device model*, the shell part is designed to adapt to different FMS configurations. For the fidelity of the virtual FMS model, a *transfer handler model* has a set of device-level commands imitating the physical mechanism of a transfer. As a result, we can expect more accurate simulation results. The *flow controller model* makes decisions on firable transfers based on decision variables, which are maintained by the *state manager model*. For the implementation of the proposed virtual FMS model, this paper employs Discrete Event Systems Specifications (DEVS) formalism, which supports the specification of discrete event models in a hierarchical, modular manner. The proposed virtual FMS model has been implemented and tested with many examples.

Keywords: Virtual FMS; Virtual factory; FMS prototyping; FMS simulation

1. Introduction

As product life cycles are reduced in the continuously changing marketplace, modern manufacturing systems must have sufficient responsiveness to adapt their behaviors efficiently to a wide range of circumstances [7]. To respond to these demands, including high productivity and production flexibility, the use of a flexible manufacturing system (FMS) has been widely accepted. A flexible manufacturing system is an integrated production system composed of automated workstations such as computer numerically controlled (CNC) machines with tool change capability, a hardware handling system and storage system, and a computer control system which controls the operations of the whole system.

The design of an FMS requires high investment, and decisions at this stage have to be made very carefully to ensure that the highly automated

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manufacturing system will successfully satisfy the demands of an ever-changing market. Simulation is an essential tool for the design and analysis of complex systems that cannot be easily described by analytical or mathematical models [3,4]. It is useful for calculating utilization statistics, finding bottlenecks, pointing out scheduling errors and even for creating manufacturing schedules. Traditionally, various simulation languages, including ARENA® and AutoMod®, have been used for the simulation of manufacturing systems [2]. Since those simulation languages focus on the representation of independent entity flows (job flows) between processes, their approach is commonly referenced to as a *transaction-oriented* approach. On the other hand, the *object-oriented* approach is based on a set of object classes that model the behavior of real system components.

The object-oriented modeling (OOM) paradigm is a way of thinking based on modeling objects from the real world and then using the model to build a language-independent design organized around those objects [8]. Since the OOM has fully demonstrated to be an effective technique for modeling complex software systems, quite a few researchers have tried to apply the OOM technique to the design and simulation of manufacturing systems. Narayanan et al. [17] reviewed diffused object-oriented methodologies to design manufacturing system software models. Their work also includes a framework of analysis for production system modeling. Kovacs et al. [1] used the object-oriented design paradigm to improve the reusability of FMS components. Anglani et al. [2] proposed a procedure to develop FMS simulation models, based on the unified modeling language (UML) analysis/design tools and on the ARENA® simulation language. One of the features of their research is that an object-oriented design phase is integrated with an implementation phase that is made with a common transaction-oriented simulation language. Based on the OOM paradigm, different researchers have proposed various FMS modeling approaches despite the fact that they express them in different ways with different notations. For example, Choi et al. [6] proposed the JR-net modeling framework based on the OOM paradigm of Rumbaugh et al. [8], which consists of three sub-models (an object model, functional model, and dynamic model). The JR-net was developed to cope with the drawbacks of formal modeling tools (Petri-net, Event Graph, ACD), such as modeling difficulty and near-intractability. Although the JR-net modeling framework is clearly defined and well-structured, the authors did not provide the implementation strategy. Chen and Lu [16] presented an object-oriented modeling methodology to design production systems by means of the Petri-nets, the entity relationship diagram (ERD) and the IDEF0.

Other than the OOM paradigm [5,6], there is another very important concept which should be considered in today's simulation environment. With the enormous improvement of computing power, many users want to create much more realistic simulation models, which can forecast not only the production capability of the system but also the physical validity and efficiency of co-working machines. The demand results in the concept of virtual factory (VF), which can be described as a model executing manufacturing processes in computers as well as the real world [7,11–15]. To implement a virtual FMS, it is necessary to construct digital models for all physical and logical elements (entities and activities) of a real FMS. Onosato and Iwata [11] identified two requirements of virtual manufacturing systems, which are application independence and structural analogy, and suggested the architecture of virtual manufacturing systems consisting of virtual physical systems and virtual informational systems. Iwata et al. [12] presented the architecture of virtual manufacturing systems for modeling and distributed simulation. Huang and Yeh [13] used the colored timed Petri-net (CTPN) to implement a virtual factory emulator. For the effective building of a virtual environment for simulation, Ye and Lin [14] proposed an approach of extracting the useful data from a two-dimensional logical simulation. Lin et al. [15] tried to represent a virtual factory in an analytical form so that existing mathematical analysis could be applied. To summarize from the previous work on the topic of VF, some aimed at developing the overall concept and architecture of VF, while others focused on the modeling scheme of VF; however, these schemes are more conceptual than realistic, for their results are either too coarse or somewhat fragmentary. Obviously, we can benefit greatly from VF, but it is still difficult and time-consuming to build.

The objective of this paper is to develop an object-oriented methodology for the modeling and simulation of a virtual FMS. For the implementation of the